GEOPHYSICAL SURVEYS FOR ASSISTING IN DETERMINING THE GROUND WATER RESOURCES KAUPULEHU AREA OF NORTH KONA ISLAND OF HAWAII

Blackhawk Geometrics Project Number 9936KSB

Prepared For:

KAMEHAMEHA SCHOOLS BISHOP ESTATE

BLACKHAWK
GEOMETRICS

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99215KSB
August 16, 1999

RECEIVED
AUG 18 1999
TOM NANCE
WATER RESOURCE ENGINEERING

TN ____
GF ____
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GS ____
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ACCTG ____
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JOB ____

Manabu Tagomori, P.E.
Water Resources Manager
Kamehameha Schools Bernice Pauahi Bishop Estate
567 South King Street
Honolulu, Hawaii 96813

Ph (808) 523-6200
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Re: TDEM Surveys on KSBE Property in Kaupulehu, North Kona, Hawaii
Blackhawk Geometrics Project Number 9936KSB

Dear Manabu:

Enclosed are three copies of our final report for the Kaupulehu project. The report contains TDEM data taken by Blackhawk from three different investigations (1990, 1993, and 1999) on KSBE property in the North Kona District, of Hawaii. A copy of the report has been sent to Tom Nance.

We appreciated the opportunity to work with you again on this project. If KSBE has any other need for geophysical surveying or consultation, we would be pleased to provide assistance. If you have any questions, please do not hesitate to call.

Sincerely,
BLACKHAWK GEOMETRICS

Richard J. Blohm
Senior Geologist

RB:lm

Enclosures

cc: Tom Nance

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August 16, 1999

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1.0 INTRODUCTION

This report contains the results of surface geophysical surveys conducted to assist in determining the ground water resources in the Kaupulehu area of North Kona, Island of Hawaii. The surveys were performed by Blackhawk Geometrics (Blackhawk) for Kamehameha Schools Bishop Estate (KSBE) from July 28 to August 1, 1999. The geophysical method employed during the survey was Time Domain Electromagnetic (TDEM) soundings. During the surveys, TDEM soundings were positioned on KSBE property located both above and below Highway 190 near the Hualalai Ranch as shown in Figure 1-1. TDEM survey data previously acquired on KSBE property (1990 and 1993) has been incorporated into this report.

The Kaupulehu area of the Island of Hawaii is in the North Kona District on the west portion of the island. The main geologic feature mapped in this area of the island is the elongated northwest rift zone associated with the Hualalai Volcano. The northwest rift zone extends from the summit of Hualalai Volcano through Hualalai Ranch to the coastline near Makolea Point (Fiske and Jackson, 1972). Several cinder and spatter cones are mapped in the Kaupulehu study area (Stearns and Macdonald, 1946) which appear to be associated with the northwest rift zone. A portion of the study area has also been covered by the recent Kaupalehu Lava Flow (dated 1800-1).

The main objective of the geophysical survey was to assist in characterizing the hydrologic regime in the Kaupulehu study area for a proposed ground water well. Groundwater resources can occur on the Island of Hawaii mainly in two modes:

- In a basal mode, where a lens-shaped body of fresh water floats on saline water.
- In a high-level mode, where the groundwater occurrence is controlled by subsurface damming structures.

These two types of groundwater occurrences are illustrated in Figure 1-2. The surficial volcanic rocks are generally highly permeable, and this allows rainwater to infiltrate directly downward through the island mass. The basal groundwater lens extends from the outer edges of the subsurface structures (i.e., dikes) to a discharge area near the shoreline. From the previous TDEM surveys in the Kaupulehu area by Blackhawk (1990 and 1993), groundwater damming structures were mapped. The potential for high-level groundwater occurrence was inferred beneath Sounding H2, which is located at 2,400 ft elevation. At the request of KSBE, additional TDEM soundings were positioned both north and east of Sounding H2 to further define the subsurface structures in the study area.

Previous TDEM surveys on the Hawaiian Islands have reliably mapped the boundary between fresh water in the basal mode and high-level water occurrences. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and completion depths.

Explanation

- K1 — 1999 TDEM Soundings
- 1 — Previous TDEM Soundings (1990 & 1993)
- A-A' — Section Line
- 1 (6.9) — Well, Water Level (Feet)

True North 10° Magnetic North

Hawaii

Survey Location

0 2000 4000 6000

Scale in Feet
Contour Interval 40 Feet

Blackhawk Geometrics
Golden, Colorado

Location Map

Kaupulehu Area
Kamehameha Schools Bishop Estate
North Kona, Hawaii

Project No. 9936KSB Figure: 1-1

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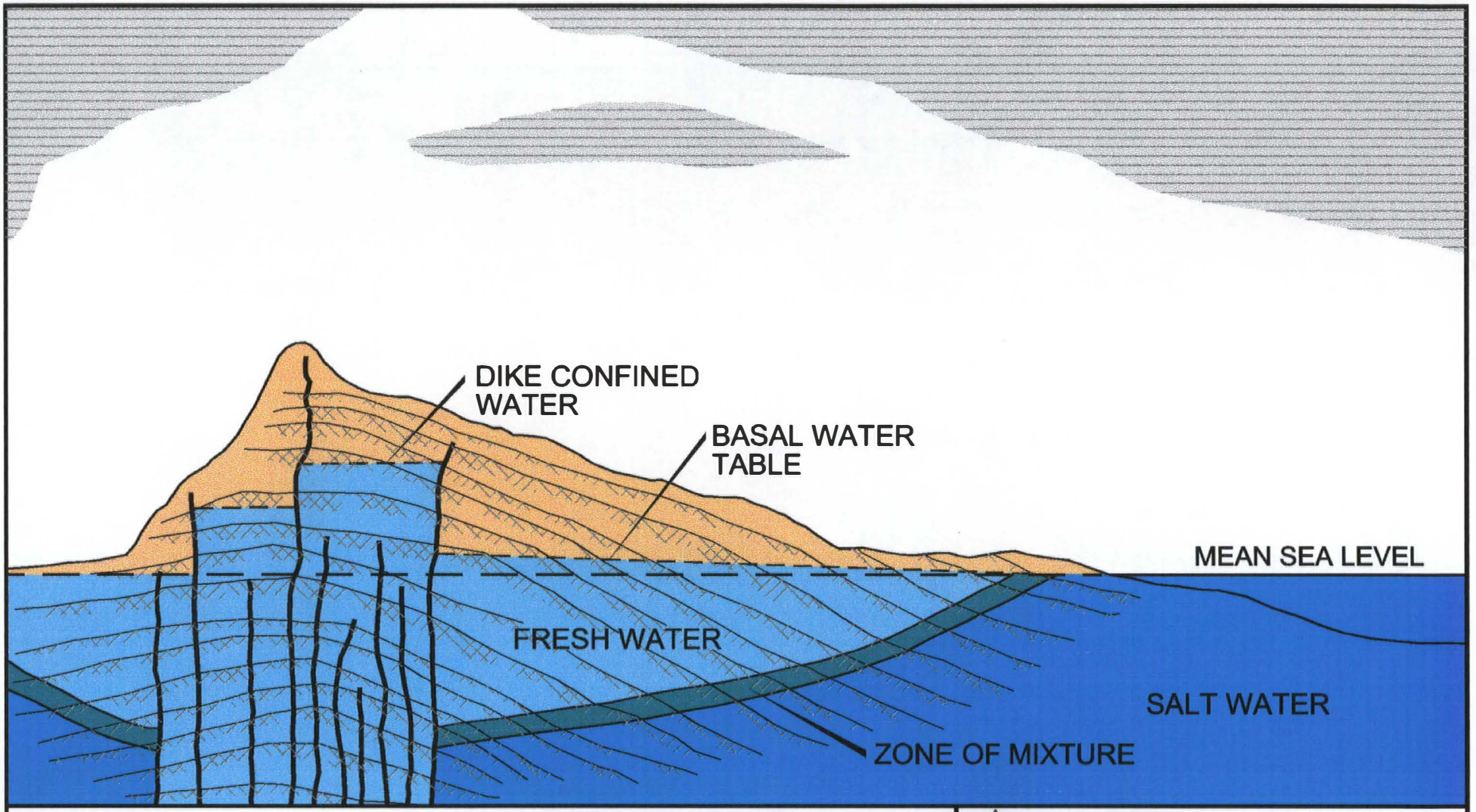

BLACKHAWK GEOMETRICS

Schematic Hydrogeologic Cross Section

Kamehameha Schools Bishop Estate
Island of Hawaii

Project No. 9936KSB Figure: 1-2

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2.0 DATA ACQUISITION AND LOGISTICS

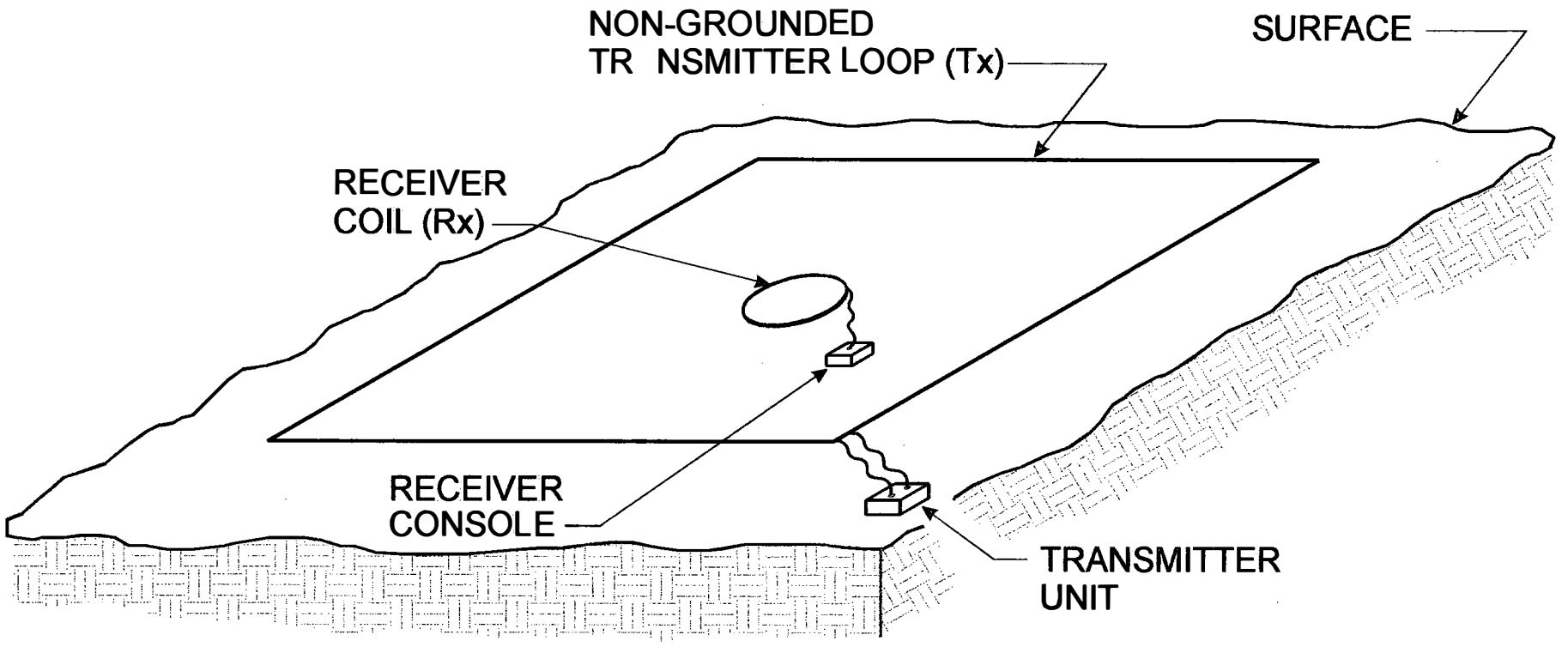
The geophysical equipment used for the Time Domain Electromagnetic (TDEM) surveys was the Geonics EM37 System. The EM37 system consists of both a portable transmitter and receiver. TDEM measurements were acquired using a central-loop sounding array (Figure 2-1) at each site. With this array, measurements are recorded with a receiver at the center of transmitter loops laid on the ground surface. For data quality control comparisons, two additional offset measurements were also made at surveyed locations near the center of each loop. The transmitter loops are constructed with 12-gauge insulated copper wire. The dimensions of each of the square transmitter loops at the Kaupulehu study area were measured at 1,500 ft by 1,500 ft. A 2.8 kW transmitter was placed in each sounding loop to drive current of 14 amperes at base frequencies of 3 Hz and 30 Hz. At the center of each transmitter loop, the time derivative of the vertical magnetic field was recorded with a receiver coil with an effective area of 100 m^2.

The data acquired at each sounding consisted of measurements at five receiver gain settings and two transmitter frequencies in order to assure data quality and to obtain data over the largest time interval possible. Data quality was excellent, due to efforts made in the field in positioning the soundings away from potential cultural noise sources (i.e., powerlines). The data from each sounding was stored in the field on an Omnidata polycorder and, subsequently, transferred to a PC for nightly processing. A brief technical note describing the principles of TDEM is given in Appendix A.

Sounding loop locations were measured by compass and hip-chain from known landmarks (i.e., bench mark, road). A total of five soundings were completed during this study at the Kaupulehu site. A daily log of field activity is given in Table 2-1. The elevation of each sounding center was measured using an altimeter/barometer. The altimeter/barometer was adjusted during the course of a day at the 1,949 ft elevation bench mark along Highway 190 as shown in Figure 1-1. The TDEM loop locations were selected in conjunction with representatives of KSBE and Blackhawk. The loop locations were based on property ownership, exploration objectives, and access. Due mainly to the required size of transmitter loops, limited access, and rough volcanic terrain, only one TDEM sounding was accomplished per day of fieldwork.

TABLE 2-1
DAILY LOG OF FIELD ACTIVITIES

DATE, 1999	ACTIVITY
July 22	Mobilize geophysical equipment from Golden, CO, to Kona, HI.
July 27	Mobilize Blackhawk personnel from Golden, CO, to Kona, HI. Retrieve geophysical equipment from airfreight and organize into field vehicles. Test TDEM equipment.
July 28	Meet with KSBE representatives and consulting hydrologist in Kona to discuss Kaupulehu project. Begin TDEM survey with data acquisition on Sounding K1, mauka Highway 190.
July 29	TDEM data taken on Sounding K2, mauka Highway 190.
July 30	Acquire TDEM data on Sounding K3, mauka Highway 190.
July 31	Take TDEM data on Sounding K4, makia Highway 190.
August 1	Acquire TDEM data on Sounding K5, makia Highway 190.
August 2	Demobilize geophysical equipment from Kona, HI, to Golden, CO.
August 3	Demobilize Blackhawk personnel from Kona, HI, to Golden, CO.



BLACKHAWK GEOMETRICS

Schematic layout of TDEM Central-Loop Array with measurement locations of Tx and Rx

Figure: 2-1

Project No. 9936KSB

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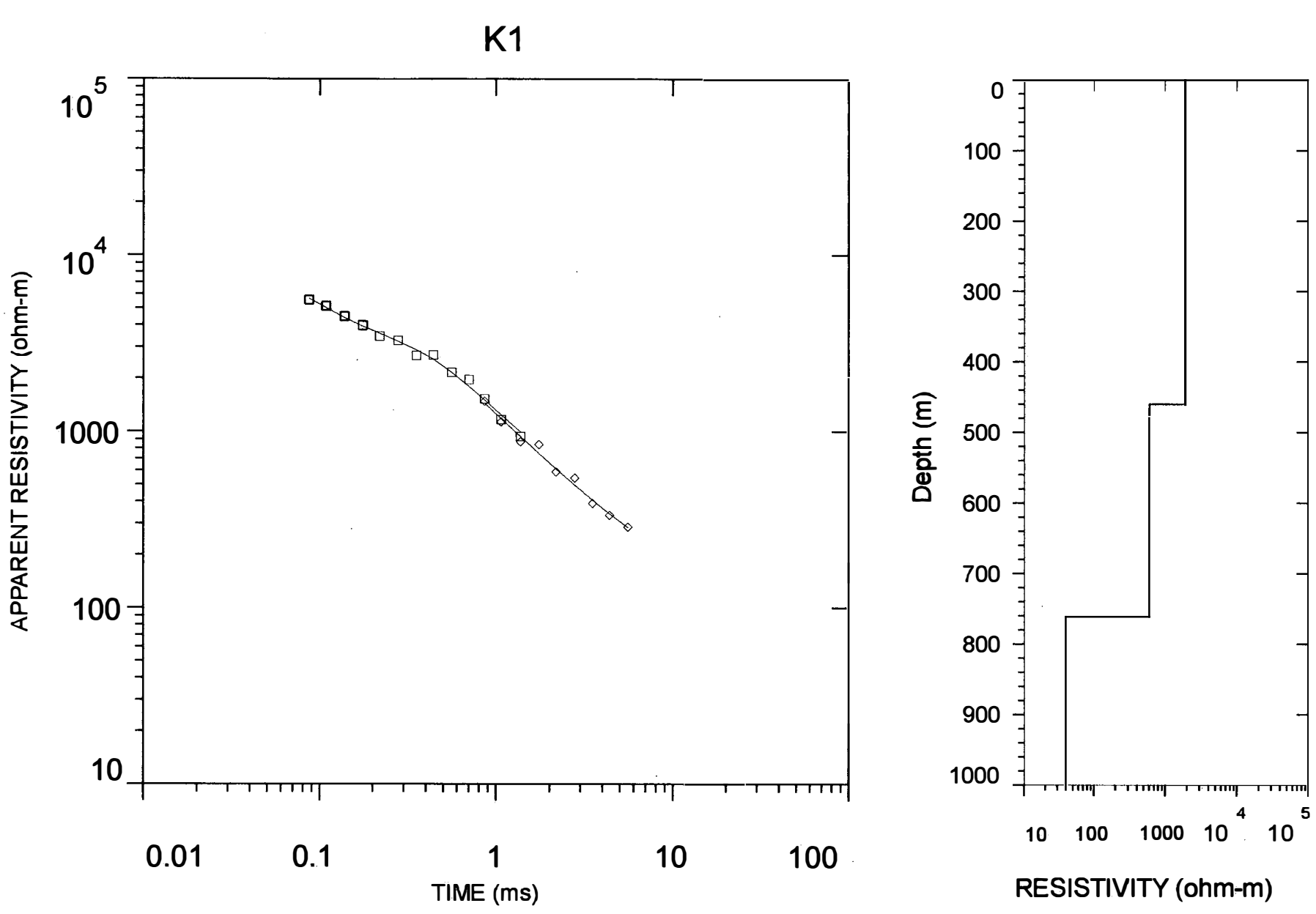
3.0 DATA PROCESSING

The TDEM field data acquired each day was transferred from the Omnidata polycorder to a PC. The first step in processing the TDEM data is to average the electromotive forces (emfs) recorded with the receiver. Next, the recordings made at different amplifier gains and frequencies were combined to give one transient decay curve with the program TEMIXXL (Interpex LTD). With this program, voltages measured with the TDEM receiver are transformed into apparent resistivity verses time gate. The apparent resistivity curve is interpreted by inversion to a one-dimensional (1-D) geoelectric section that matches the observed decay curve.

The inversion program requires an initial estimate of the geoelectric section, including the number of layers and the thicknesses and resistivities of each of the layers. The program then adjusts these parameters so that the model curve converges to best fit the curve formed by the field data. The inversion program does not change the number of layers within the model, but allows all other parameters to change freely, or they can optionally be fixed constant. To determine the influence and best fit of the number of layers on the solution, separate inversions with different numbers of layers are run. The model with the fewest number of layers which best fits the data is used.

An example of the output of the inversion program for Sounding K1 is shown on Figures 3-1 and 3-2. Figure 3-1 shows the measured data points (in terms of apparent resistivity) superimposed on a solid line. The solid line represents the computed forward model of the geoelectric section shown on the right. Tabulated inversion parameters and results consisting of measured field data, computed data for best match solution, and inversion errors are given on Figure 3-2.

The apparent resistivity curves and data sheets for the five TDEM soundings taken during this survey are given in Appendix B.



BLACKHAWK GEOMETRICS

TDEM Inversion Results
Sounding K1
Kamehameha Schools Bishop Estate
North Kona, Hawaii

Figure: 3-1

Project No. 9936KSB

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DATA SET: K1

CLIENT: KSBE
LOCATION: KAUPULEHU, HUALALAI RANCH
COUNTY: NORTH KONA
PROJECT: KAUPULEHU
LOOP SIZE: 457.000 m by 457.000 m
COIL LOC: 0.000 m (X), 0.000 m (Y)
SOUNDING COORDINATES: E: 100.0000 N:
DATE: 07-28-99
SOUNDING: 1
ELEVATION: 681.20 m
EQUIPMENT: Geonics PROTEM
AZIMUTH:
TIME CONSTANT: NONE
1.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 8.219 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	CONDUCTANCE (Siemens)
			681.2	
1	1958.3	459.7	221.4	0.234
2	606.2	301.8	-80.36	0.497
3	40.04			

ALL PARAMETERS ARE FREE

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 7 RAMP TIME: 210.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	1608.8	1564.7	2.74
2	0.108	1052.3	1087.6	-3.35
3	0.138	694.8	712.0	-2.47
4	0.175	456.2	464.0	-1.72
5	0.218	325.4	307.9	5.38
6	0.278	191.4	195.4	-2.05
7	0.351	143.7	128.8	10.38
8	0.438	81.87	89.48	-9.29
9	0.558	62.91	63.06	-0.232
10	0.702	40.72	46.79	-14.88
11	0.858	35.91	36.69	-2.16
12	1.06	31.22	28.51	8.69
13	1.37	23.20	21.20	8.64

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 8 RAMP TIME: 210.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
14	0.857	37.97	39.07	-2.88
15	1.06	32.95	30.76	6.65
16	1.37	25.81	23.34	9.55
17	1.74	14.95	17.89	-19.64
18	2.17	14.77	13.88	5.98
19	2.77	9.05	10.37	-14.58
20	3.50	8.24	7.74	6.04
21	4.37	5.96	5.79	2.74
22	5.56	4.12	4.16	-1.09

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.96				
P 2	-0.04	0.37			
P 3	0.02	-0.06	0.85		
T 1	0.05	0.26	-0.02	0.85	
T 2	-0.07	-0.34	0.03	0.21	0.70

BLACKHAWK GEOMETRICS

TDEM Inversion Results
Sounding K1
Kamehameha Schools Bishop Estate
North Kona, Hawaii

Figure: 3-2

Project No. 9936KSB

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4.0 INTERPRETATION RESULTS

4.1 General

The main objective of TDEM soundings is to derive the resistivity layering (geoelectric section) of the subsurface. The translation of resistivity layering into hydrologic information is generally accomplished by two methods. These include:

1) Using available knowledge about the relation between resistivity values and local hydrology. From more than 25 previous TDEM surveys on the Hawaiian Islands, it has been observed that volcanic rocks saturated with salt water exhibit resistivities typically less than 5 ohm-m. Conversely, volcanic rocks that are dry and unweathered or fresh water saturated, exhibit high resistivities (generally greater than 500 ohm-m). Weathered volcanics or ash flows and intrusives often exhibit intermediate resistivities (about 10 ohm-m to 100 ohm-m).

   Applying this information, characteristic ranges of resistivities expected for local hydrogeologic units for the Kaupulehu study area are shown in Figure 4-1. It should be noted that some overlap in resistivity values occur. In these cases, other factors are used to infer the geologic/hydrologic unit in question. For example, a low resistivity unit (i.e., less than 10 ohm-m) occurring at an elevation above sea level is assumed to be caused by either weathered rock units or intrusives (i.e., dikes) instead of salt water saturated formations.

2) Another method is to calibrate the geophysical interpretation at a well. There were two wells (1 and 2) used for comparison to the 1990 TDEM data. The location of the two wells is between Soundings 1 and 2. The two wells have static water levels (head) of 6.9 ft and 12.6 ft, respectively. The large difference in head over the short distance (about 100 ft) can be explained by possible geologic structures (i.e., dikes, faults) that affect groundwater flow or possible error in head measurements. The TDEM soundings show a complicated area near the two wells with geologic structures being inferred between Soundings 2 and A. The calculated head from Sounding A is about 10.8 ft, which appears reasonable for this area.

Where a very conductive layer (less than 5 ohm-m) is detected below sea level in the TDEM measurement, the layer is interpreted to be caused by salt water saturated volcanics. Static fresh water levels can be calculated from these soundings by using the Ghyben-Herzberg relation as illustrated in Figure 4.2. The Ghyben-Herzberg relation states that for every 1 ft of fresh water above sea level, approximately 40 ft of fresh water will exist below sea level. However, hydrostatic equilibrium is assumed for these measurements, and this relation is not expected to apply to soundings in close proximity to major geologic structures (i.e., rift zones, dikes) which can alter groundwater flow. Generally, rift zones contain vertical dikes and faults, which can run parallel and subparallel to the main rift orientation for hundreds of feet within a central rift corridor. Intersecting dikes are common in rift zones, and groundwater can become compartmentalized between the dikes. Rift zones may also contain a series of cinder and spatter cones, which generally trend linearly away from a central volcano.

4.2 Geoelectric Cross Sections

The results of the inversion of the individual TDEM soundings are the1-D resistivity layering as a function of depth. The TDEM results from individual soundings can be linked together to produce a 2-D geoelectric cross-section along a survey transect. The geoelectric cross-section can be correlated to geologic units by comparison with available geologic information. The locations of soundings from previous TDEM surveys (1990 and 1993) on KSBE property have been incorporated into this report. From these combined data sets, two new geoelectric cross-sections were constructed. The location map of the Kaupulehu area and the directions of the geoelectric cross sections are shown on Figure 1-1.

Geoelectric Cross-Section A-A'

Figure 4-3 shows the results of five TDEM soundings presented as a west to east trending geoelectric cross-section (A-A'), in which layers that exhibit similar resistivity values have been linked together.

The interpreted geoelectric section from the five soundings consists of three layers. The uppermost layer of each sounding, with resistivities ranging from about 1356 ohm-m to 5658 ohm-m, is interpreted to represent dry unweathered volcanics above mean sea level (msl). The second layer in the cross-section exhibits resistivities from about 360 ohm-m to 1138 ohm-m. It is also interpreted as unweathered volcanics above msl; and where it occurs below msl, it is expected to be saturated with fresh-brackish basal water. The third layer (green) in the section, beneath Soundings H1, K2, K1, and K3, exhibits an intermediate to low resistivity ranging from about 85 ohm-m to 7.8 ohm-m. The resistivity values of the third layer are interpreted to be influenced by lateral discontinuities (i.e., dikes, faults). Because of rapid lateral variations in resistivities between Soundings H2, K2, K1, and K3, the interpreted resistivity stratification may not represent true formation resistivities. The exact position and width of the discontinuous layers is uncertain due to TDEM data density. Since the sea water interface was not interpreted beneath any of the soundings, the elevation of the groundwater table cannot be calculated by the Ghyben-Herzberg relation. However, because the top of the intermediate resistivity layer (53 ohm-m) beneath Sounding H1 is interpreted to be about 450 ft below msl, the potential for fresh water occurring beneath Sounding H1 is good. The top of the low resistivity layer (7.8 ohm-m) beneath Sounding K3 is interpreted to be about 250 ft below msl, and a modest layer of fresh-brackish water may occur at this location.

Sounding H2 exhibits high resistivity values (187 ohm-m to 1356 ohm-m) throughout the effective exploration depth (about 750 ft below msl) of the data. This sounding is interpreted to be located between geologic/hydrologic structures observed on either side (Soundings H1 and K2). With the existing TDEM data density, the hydrogeologic boundaries are placed midway between the soundings, and the potential for high-level groundwater appears to exist beneath Sounding H2.

Geoelectric Cross Section B-B'

The results for B-B' are shown in Figure 4-4 as a south to northeast trending cross-section. The upper two layers of the cross-section display resistivities ranging from about 478 ohm-m to 5372 ohm-m. These upper two layers are interpreted to be unweathered volcanics above sea level; and where the second layer occurs below sea level, it is interpreted to be saturated with fresh-brackish basal water. Because Sounding H2 is interpreted to be located above the geologic/hydrologic structure and the section shows a high resistivity layer (187 ohm-m) below msl, the potential for high-level groundwater beneath this area appears good. The third layer beneath Soundings H3 and K5 (green) with resistivities values from 17 ohm-m to 8.3 ohm-m is interpreted to be in a structurally complex area. Because of the rapid lateral variations in resistivities, the interpreted resistivity stratification may not represent true formation resistivities beneath these soundings, and the exact position and width of the discontinuous layers is uncertain. The salt water interface was not interpreted beneath Soundings H3 and K5; and therefore, the elevation of the water table cannot be estimated by the Ghyben-Herzberg relation. The third layer beneath Sounding K4 (blue) exhibits a resistivity of 3.7 ohm-m and is interpreted to represent salt water saturated volcanics. The thickness of the fresh-brackish water lens is estimated to be 323 ft beneath Sounding K4.

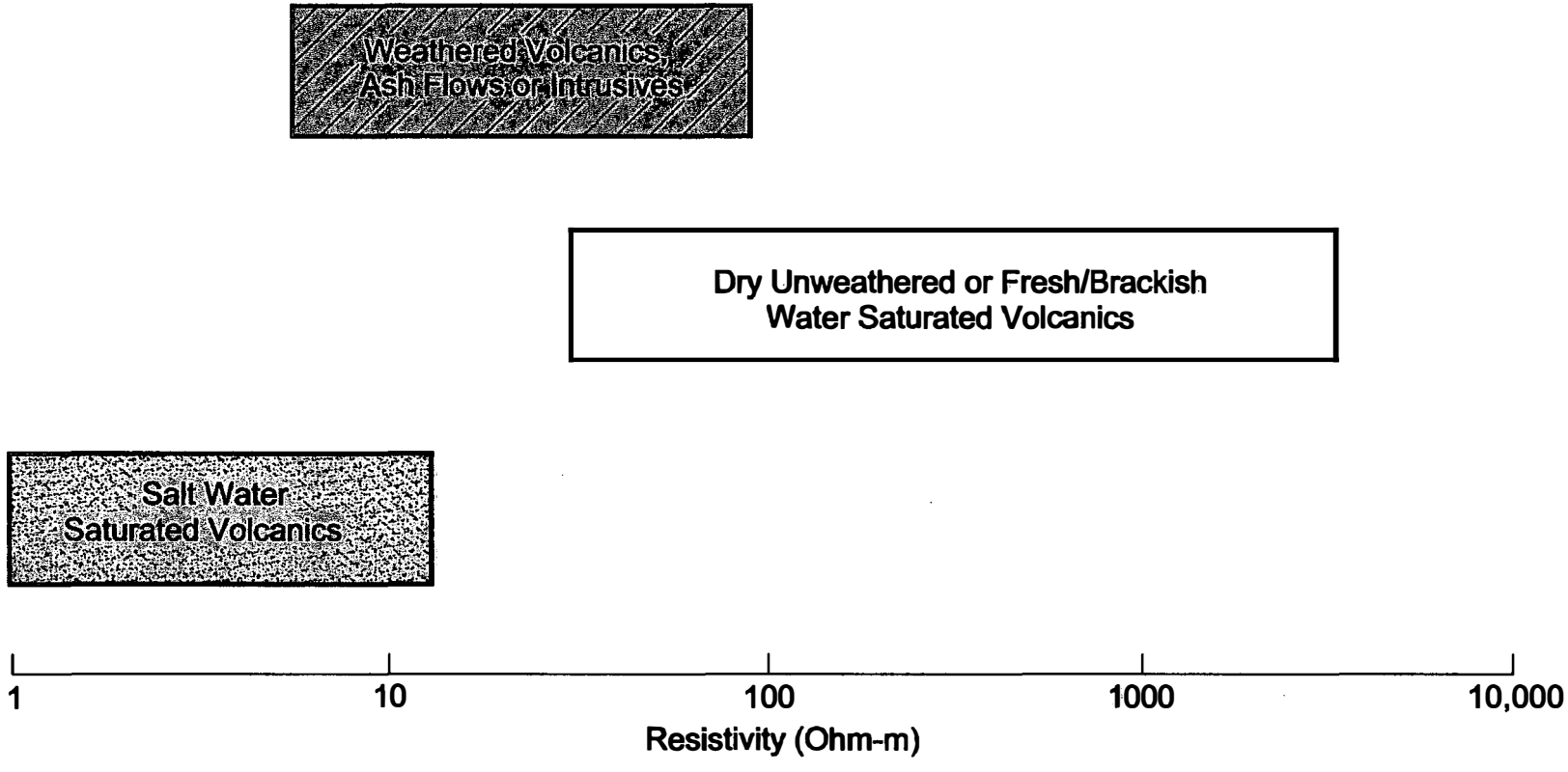
4.3 Hydrogeologic Interpretation

The results of the TDEM investigations from all the data sets (1990, 1993, and 1999) are combined and have been further summarized in Figure 4-5. The soundings are separated into three main groups and are color coded:

1. Three soundings A, B, and K4 (blue), in which a layer of low resistivity was detected below sea level. A fresh-brackish water lens is expected to occur in the basal mode beneath these three soundings. The approximate thickness of the fresh-brackish water lens is expected to vary from about 430 ft at Sounding A, to 340 at Sounding B, and 320 ft beneath Sounding K4.
2. A group of eleven soundings (1, 2, 3, 4, C, H1, H3, K1, K2, K3, and K5) which are interpreted to be influenced by lateral discontinuities (i.e., dikes) and geologic/ hydrologic groundwater damming structures are inferred (green). Intermediate resistivity values occur both above and below msl in this area. Groundwater levels, water quality, and production are expected to be highly variable in these areas.
3. Sounding H2, in which high resistivity values are interpreted to the effective exploration depth of about 750 ft below msl (yellow). In the area of this sounding, the potential for high-level groundwater exists.

The accuracy of determining the depth to the salt water interface from TDEM soundings is estimated to be ±5% of the total depth calculated in the sounding result (e.g., from the ground surface to the salt water interface). The accuracy of determining the interpreted groundwater damming structures at the Kaupulehu area is determined mainly by TDEM data density (station spacing).

From the summary map, the lower (makia) boundary of the inferred geologic/hydrologic discontinuity is placed upslope from Sounding B at about the 1520 ft elevation level. From there, it continues roughly along contour to the east, where it rapidly increases elevation (1900 ft above msl) upslope from Sounding K4. The exact cause of the rapid increase upslope near Sounding K4 is unknown, but it appears to be structure (i.e., dike) related. The inland (mauka) boundary of the inferred discontinuity is approximately placed above Sounding H3 and between Soundings H1, and H2; and H2, and K2. The position of the inland boundary appears to place Sounding H2 above inferred geologic/ hydrologic groundwater damming structures, which are roughly defined on three sides. The northwest rift zone from Hualalai Volcano appears to intersect the Kaupulehu area at a N 60° W bearing approximately above the Hualalai Ranch. This feature may have an affect on groundwater flow in the Kaupulehu area.



BLACKHAWK GEOMETRICS

Characteristic Resistivity Ranges

Kamehameha Schools Bishop Estate

Island of Hawaii

Project No. 9936KSB Figure: 4-1

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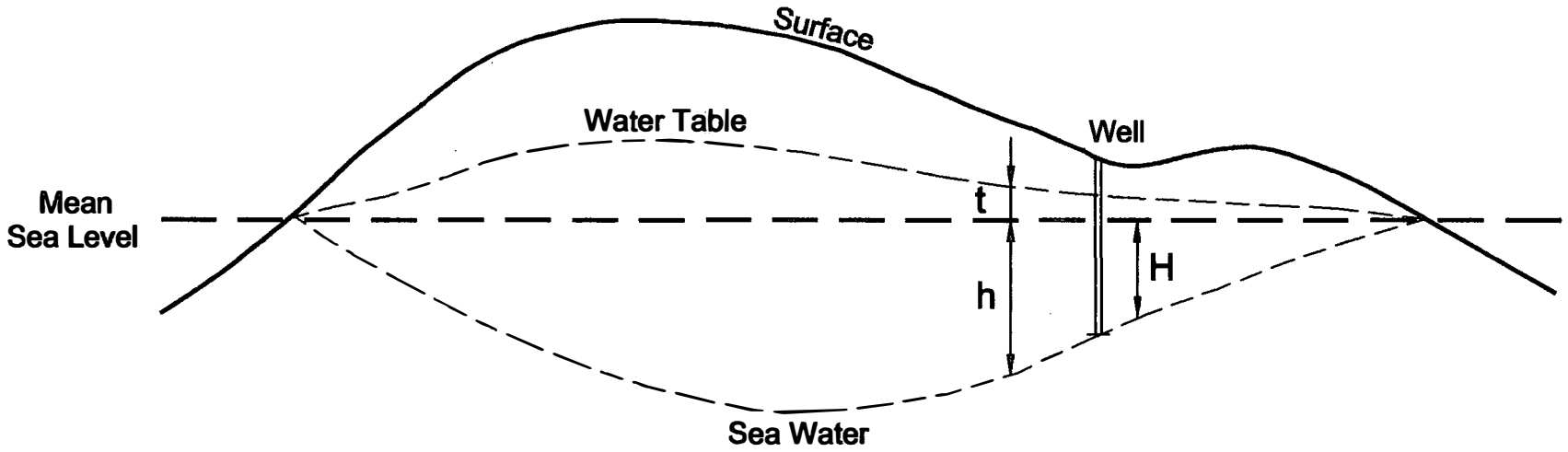

t = 1/40 (h)

From: Herzberg

BLACKHAWK GEOMETRICS

Illustration of the Ghyben-Herzberg Principle

Kamehameha Schools Bishop Estate

Island of Hawaii

Project No. 9936KSB Figure: 4-2

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A'

H1 (2320) | H2 (2340) | K2 (2435) | K1 (2235) | K3 (2240)

Sounding Number

Road

Ground Surface

Elevation (Feet)

2500

2000

1500

1000

500

0

-500

-1000

ELEVATION (FEET)

1963 | 1356 | 5658 | 2081 | 1958 | 1138 | 716 | 932 | 360 | 606

Sea Level

187

53 | 85 | 40 | 7.8

APPROXIMATE EXPLORATION DEPTH LIMIT

Discontinuity Position and Width Uncertain

Potential High-Level Ground Water

Discontinuity Position and Width Uncertain

Explanation

53 Resistivity in ohm-m

Dry unweathered or fresh-brackish water saturated volcanics

Inferred structure (possible ash flows, or intrusives) at depth

Salt water saturated volcanics

Inferred geologic/hydrologic discontinuity

500 ft.

0

1000 ft.

Horizontal Scale Exaggeration 2:1

Blackhawk Geometrics
Golden, Colorado

Geoelectric Cross-Section A-A'

Kaupulehu Area
Kamehameha Schools Bishop Estate
North Kona, Hawaii

Project No. 9936KSB Figure: 4-3

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B

B'

Bend In Section

H2	H3	K5	K4	Sounding Number
(2340)	(1885)	(1805)	(1795)	Elevation (Feet)

HWY 190

Ground Surface

1356 716 187 | 1997 478 | 2746 588 | 5372 944

Sea Level

17 | 8.3 | 3.7

APPROXIMATE EXPLORATION DEPTH LIMIT

2500 2000 1500 1000 500 0 -500 -1000

ELEVATION (FEET)

Potential High-Level Ground Water

Discontinuity Position and Width Uncertain

Basal Mode Ground Water

Explanation

53 Resistivity in ohm-m

Dry unweathered or fresh-brackish water saturated volcanics

Inferred structure (possible ash flows, or intrusives) at depth

Salt water saturated volcanics

Inferred geologic/hydrologic discontinuity

500 ft.

0 1000 ft.

Horizontal Scale Exaggeration 2:1

Blackhawk Geometrics
Golden, Colorado

Geoelectric Cross-Section B-B'

Kaupulehu Area
Kamehameha Schools Bishop Estate
North Kona, Hawaii

Project No. 9936KSB Figure: 4-4

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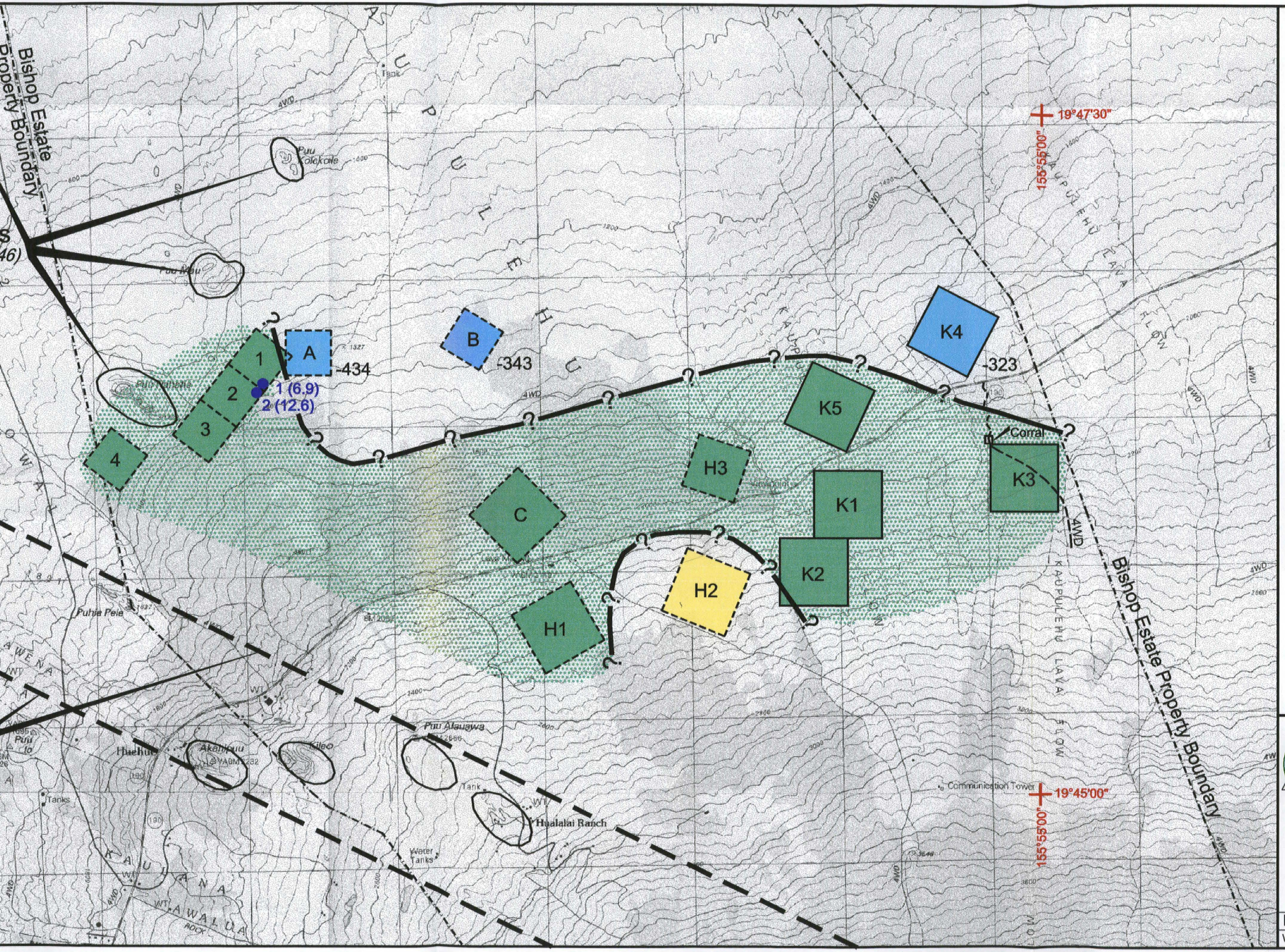
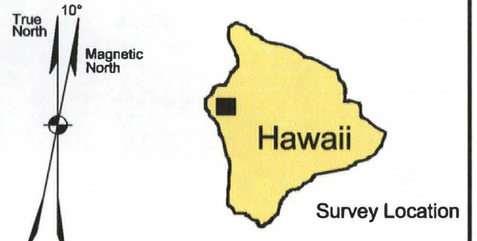


Explanation

- Soundings with a conductive layer below sea level, typical of basal groundwater
- Soundings with an intermediate resistive layer, inferring the presence of geologic structures
- Soundings with highly resistive layers, throughout the entire explored section
- 1 (6.9) — Well, Water Level (Feet)
- -323 — Estimated elevation of top of salt water interface in feet
- Inferred geologic/hydrologic discontinuity (exact position uncertain)



0 2000 4000 6000

Scale in Feet
Contour Interval 40 Feet

Blackhawk Geometrics
Golden, Colorado

Summary Map

Kaupulehu Area
Kamehameha Schools Bishop Estate
North Kona, Hawaii

Project No. 9936KSB Figure: 4-5
\projects\9936ksb\InterpMap.dwg

5.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the TDEM surveys (1990, 1993, and 1999) at the Kaupulehu area of North Kona, Hawaii, for KSBE are combined and shown in Figure 4-5. The data indicate that beneath three soundings, a lens of basal mode fresh-brackish water occurs. The thickest lens of potential fresh-brackish water resource is interpreted to occur beneath Sounding A, and it is estimated to be 434 ft. Soundings 1, 2, and 3, taken near Wells 1 and 2 (reported heads of 6.9 ft and 12.6 ft) showed intermediate resistivity layers (28 ohm-m to 43 ohm-m) slightly below msl and are interpreted to be in an area of geologic structures. The calculated head from Sounding A is about 10.8 ft, and this appears to be reasonable in this structurally complicated area.

In a large area of the survey (beneath Soundings 1, 2, 3, 4, C, H1, H3, K1, K2, K3, and K5), subsurface structures (i.e., dikes, rift zone) are interpreted, and the groundwater regime is expected to be structurally complicated with groundwater yield and quality in this area being highly variable. The groundwater resources within areas controlled by geologic structures cannot be determined directly from the TDEM sounding data.

Beneath Sounding H2, the potential for high-level groundwater is expected to exist. Groundwater damming structures are interpreted on three sides of Sounding H2; and therefore, this appears to be the best location for a high-level water occurrence.

The northwest rift zone (approximately positioned on Figure 4-5) from Hualalai Volcano appears to intersect the survey area at about a N 60° W bearing near Puu Alauawa on the Hualalai Ranch. This geologic feature is expected to have an affect on the groundwater flow in this area.

To help confirm the position of the lower and upper inferred groundwater damming structure, additional TDEM sounding data should be taken in areas of sparse data density.

REFERENCES

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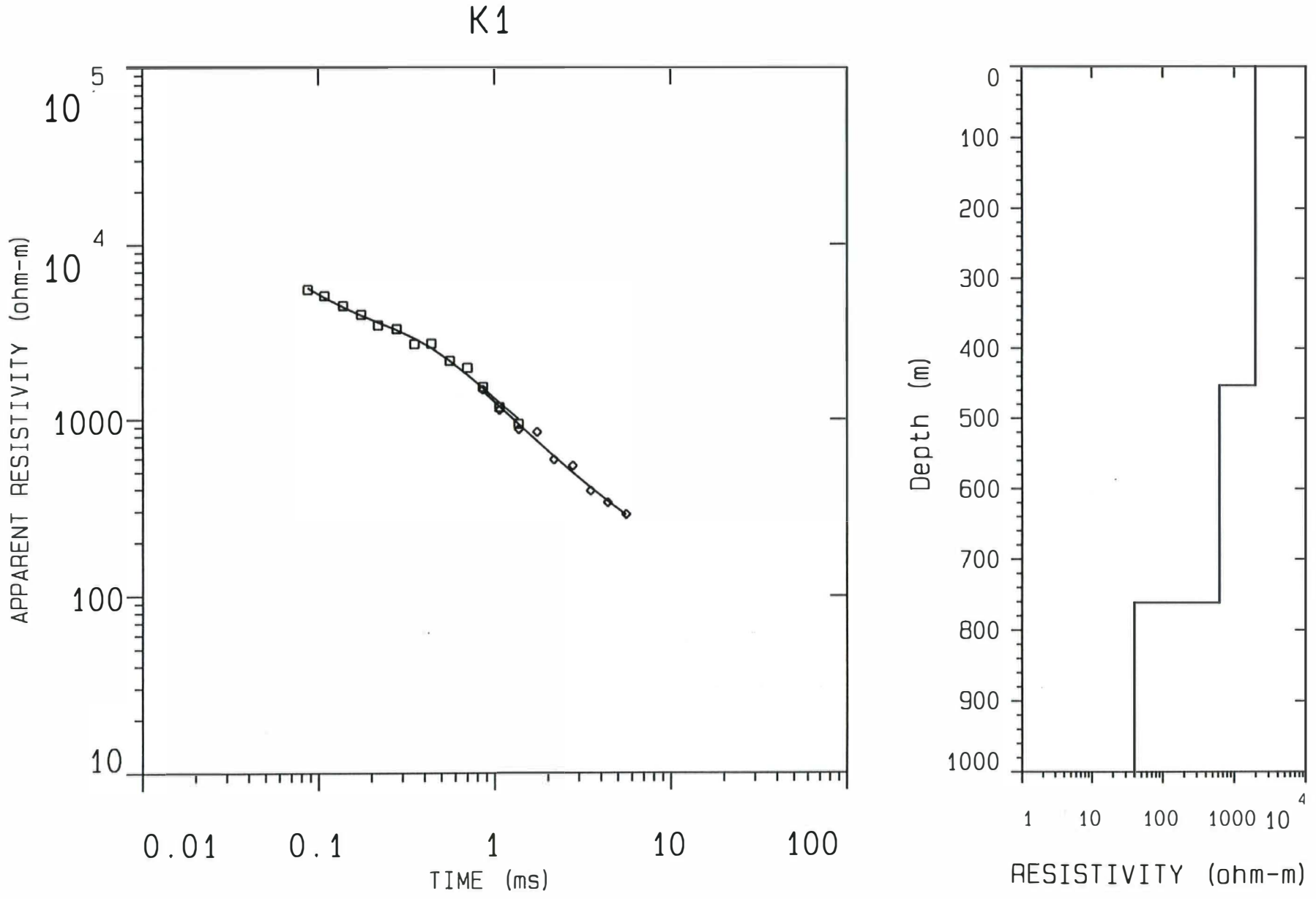
2. Fiske, R. S., and Jackson, E. D., 1972. Orientation and growth of Hawaiian volcanic rifts: The effect of regional structure and gravitational stresses: Proceedings of the Royal Society of London, ser. A. v. 329, pp. 299-326.
3. Langenheim, V.A.M., Clague, D.A., 1987. Stratigraphic framework of volcanic rocks of the Hawaiian Islands, Chap 1, Volcanism in Hawaii: U.S. Geological Survey Professional Paper 1350, Vol 1, pp. 61-63.
4. Stearns, H. T., Macdonald, G. A., 1946. Geology and ground-water resources of the Island of Hawaii, Hawaii Division of Hydrography Bulletin 9, pp. 137-149.
5. Wilt, M. J., 1991. Interpretation of time domain electromagnetic soundings near geologic contacts, Ph.D. Thesis, Lawrence Berkeley Laboratory, University of California Earth Sciences Division, pp. 185.


K1
APPARENT RESISTIVITY (ohm-m)
10^5
10^4
1000
100
10
0.01
0.1
1
10
100
TIME (ms)
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1
10
100
1000
10^4
RESISTIVITY (ohm-m)

DATA SET: K1

CLIENT: KSBE DATE: 07-28-99
LOCATION: KAUPULEHU, HUALALAI RANCH SOUNDING: 1
COUNTY: NORTH KONA ELEVATION: 681.20 m
PROJECT: KAUPULEHU EQUIPMENT: Geonics PROTEM
LOOP SIZE: 457.000 m by 457.000 m AZIMUTH:
COIL LOC: 0.000 m (X), 0.000 m (Y) TIME CONSTANT: NONE
SOUNDING COORDINATES: E: 100.0000 N: 1.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 8.219 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(FT)	CONDUCTANCE (Siemens)
			681.2	2235.0	
1	1958.3	459.7	221.4	726.4	0.234
2	606.2	301.8	-80.36	-263.6	0.497
3	40.04				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	1751.785	1958.312	2251.026
	2	390.962	606.208	914.237
	3	26.013	40.047	58.084
THICK	1	381.323	459.724	553.225
	2	231.632	301.841	400.260
DEPTH	1	381.323	459.724	553.225
	2	759.824	761.565	788.327

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 7 RAMP TIME: 210.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

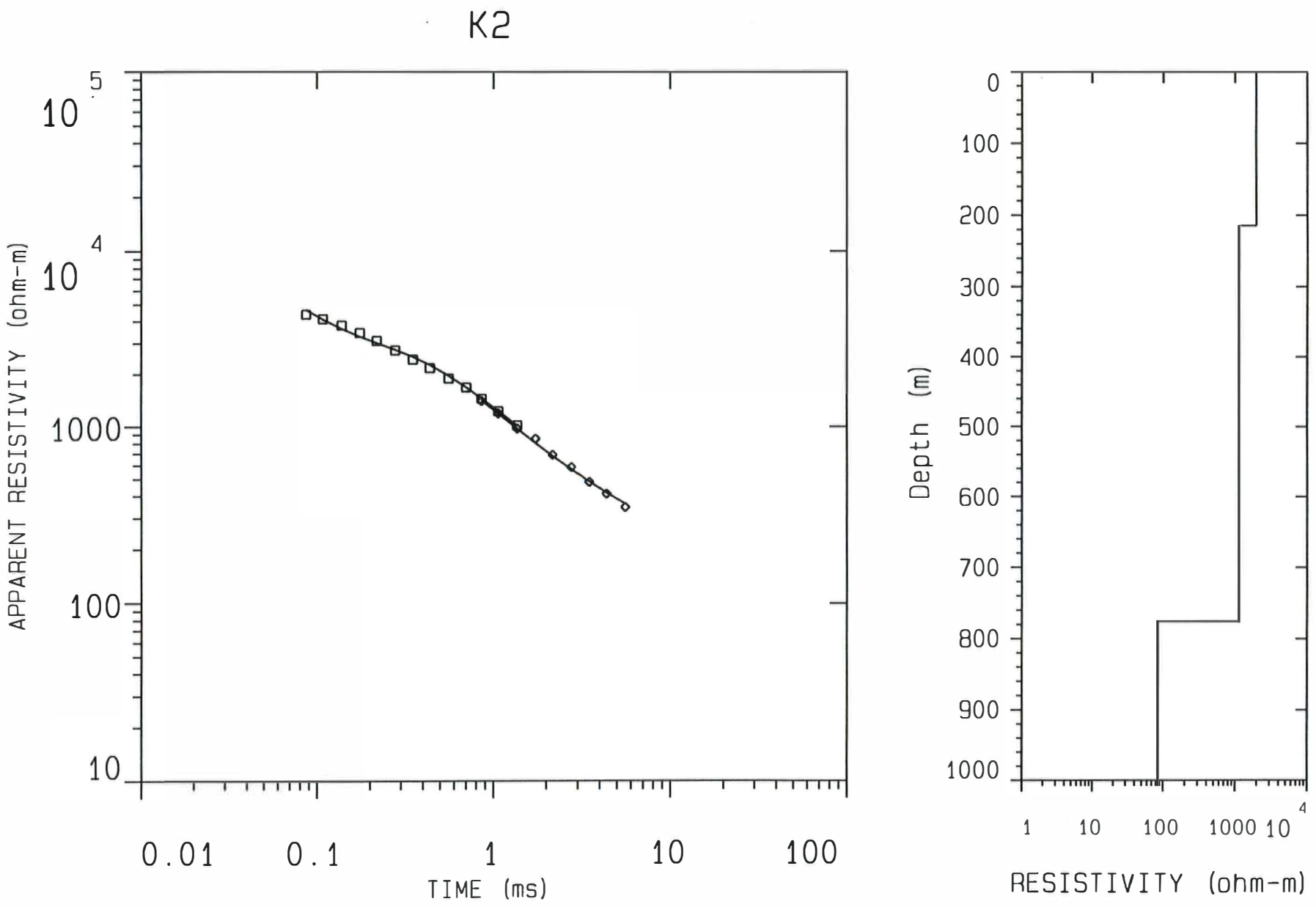
No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	1608.8	1564.7	2.74
2	0.108	1052.3	1087.6	-3.35
3	0.138	694.8	712.0	-2.47
4	0.175	456.2	464.0	-1.72
5	0.218	325.4	307.9	5.38
6	0.278	191.4	195.4	-2.05
7	0.351	143.7	128.8	10.38
8	0.438	81.87	89.48	-9.29
9	0.558	62.91	63.06	-0.232
10	0.702	40.72	46.79	-14.88
11	0.858	35.91	36.69	-2.16
12	1.06	31.22	28.51	8.69
13	1.37	23.20	21.20	8.64

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 8 RAMP TIME: 210.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
14	0.857	37.97	39.07	-2.88
15	1.06	32.95	30.76	6.65
16	1.37	25.81	23.34	9.55
17	1.74	14.95	17.89	-19.64
18	2.17	14.77	13.88	5.98
19	2.77	9.05	10.37	-14.58
20	3.50	8.24	7.74	6.04
21	4.37	5.96	5.79	2.74
22	5.56	4.12	4.16	-1.09

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.96				
P 2	-0.04	0.37			
P 3	0.02	-0.06	0.85		
T 1	0.05	0.26	-0.02	0.85	
T 2	-0.07	-0.34	0.03	0.21	0.70


K2
APPARENT RESISTIVITY (ohm-m)
10^5
10^4
1000
100
10
0.01
0.1
1
10
100
TIME (ms)
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1
10
100
1000
10^4
RESISTIVITY (ohm-m)

DATA SET: K2

CLIENT: KSBE DATE: 07-29-99
LOCATION: KAUPULEHU, HUALALAI RANCH SOUNDING: 2
COUNTY: NORTH KONA ELEVATION: 742.20 m
PROJECT: KAUPELEHU EQUIPMENT: Geonics PROTEM
LOOP SIZE: 457.000 m by 457.000 m AZIMUTH:
COIL LOC: 0.000 m (X), 0.000 m (Y) TIME CONSTANT: NONE
SOUNDING COORDINATES: E: 100.0000 N: 2.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 4.678 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(FT)	CONDUCTANCE (Siemens)
			742.2	2435.0	
1	1962.8	214.0	528.1	1732.6	0.109
2	1137.7	561.7	-33.65	-110.4	0.493
3	85.17				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	1652.091	1962.849	2618.626
	2	910.438	1137.772	1392.325
	3	71.507	85.175	102.957
THICK	1	165.629	214.081	322.136
	2	467.413	561.773	617.284
DEPTH	1	165.629	214.081	322.136
	2	764.885	775.855	794.511

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 6 RAMP TIME: 210.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

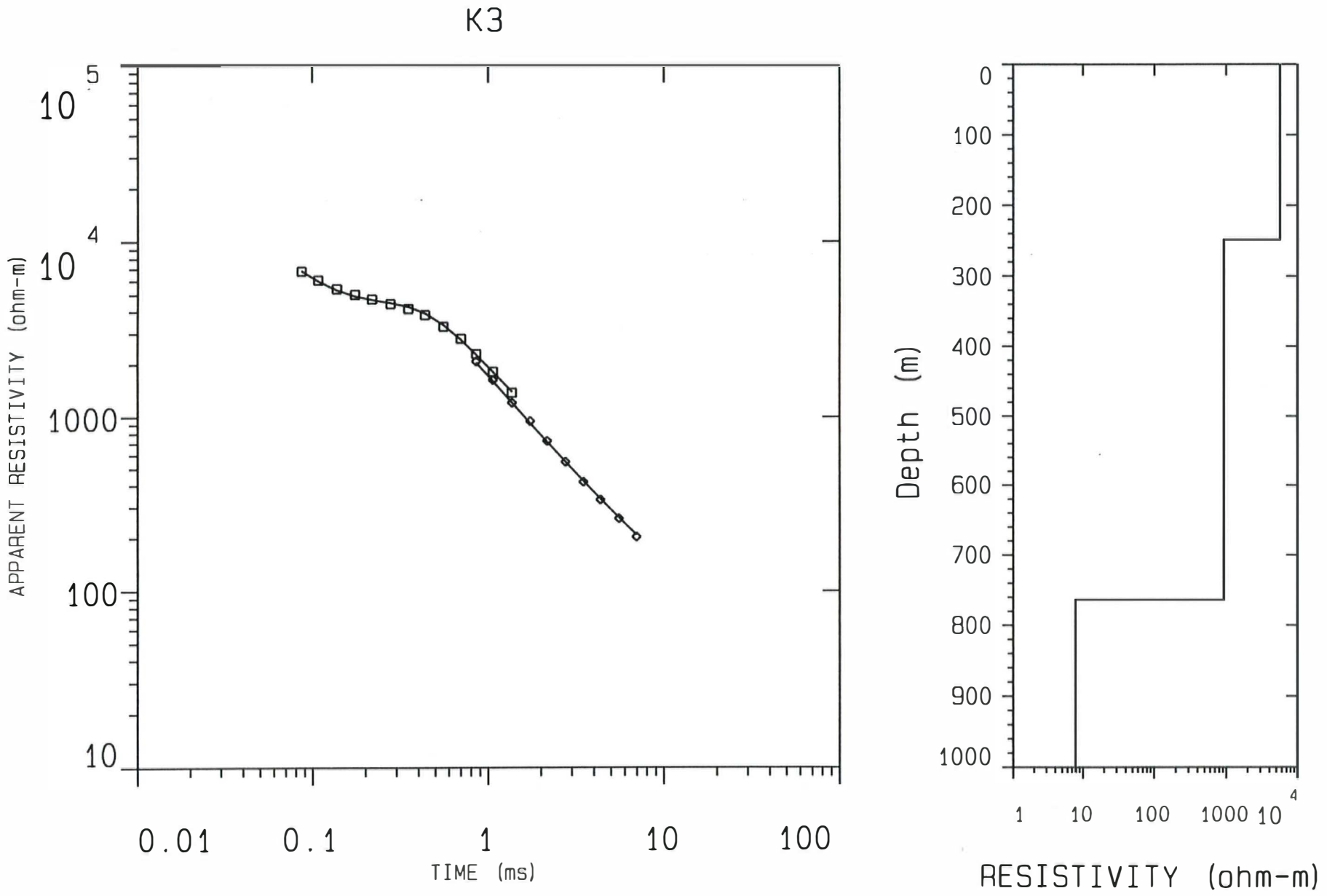
No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	2292.9	2086.5	9.00
2	0.108	1446.0	1461.1	-1.04
3	0.138	892.2	953.8	-6.91
4	0.175	569.2	614.6	-7.96
5	0.218	384.8	402.1	-4.49
6	0.278	252.7	249.9	1.11
7	0.351	168.4	160.3	4.84
8	0.438	114.6	107.9	5.80
9	0.558	76.95	72.75	5.45
10	0.702	51.76	51.75	0.0193
11	0.858	39.13	39.17	-0.0879
12	1.06	29.23	29.15	0.259
13	1.37	20.68	20.78	-0.506

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 7 RAMP TIME: 210.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
14	0.857	41.13	40.69	1.08
15	1.06	30.51	30.55	-0.146
16	1.37	22.01	22.11	-0.424
17	1.74	14.74	16.10	-9.22
18	2.17	11.69	11.94	-2.16
19	2.77	8.09	8.46	-4.52
20	3.50	6.05	6.00	0.793
21	4.37	4.37	4.28	2.23
22	5.56	3.11	2.91	6.43

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.43				
P 2	0.26	0.68			
P 3	0.06	-0.09	0.56		
T 1	0.18	0.22	0.00	0.23	
T 2	-0.10	-0.05	0.05	0.28	0.87
	P 1	P 2	P 3	T 1	T 2


K3
APPARENT RESISTIVITY (ohm-m)
10^5
10^4
1000
100
10
0.01
0.1
1
10
100
TIME (ms)
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1
10
100
1000
10^4
RESISTIVITY (ohm-m)

DATA SET: K3

CLIENT: KSBE DATE: 07-30-99
LOCATION: KAUPULEHU, HUALALAI RANCH SOUNDING: 3
COUNTY: NORTH KONA ELEVATION: 682.80 m
PROJECT: KAUPELEHU EQUIPMENT: Geonics PROTEM
LOOP SIZE: 457.000 m by 457.000 m AZIMUTH:
COIL LOC: 0.000 m (X), 0.000 m (Y) TIME CONSTANT: NONE
SOUNDING COORDINATES: E: 200.0000 N: 3.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 2.372 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(FT)	CONDUCTANCE (Siemens)
			682.7	2240.0	
1	5657.9	248.0	434.7	1426.1	0.0438
2	931.8	516.0	-81.26	-266.5	0.553
3	7.79				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	4404.595	5657.970	9208.178
	2	794.884	931.811	987.968
	3	6.333	7.798	8.961
THICK	1	227.624	248.027	294.624
	2	471.553	516.037	535.721
DEPTH	1	227.624	248.027	294.624
	2	751.178	764.064	772.808

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 7 RAMP TIME: 210.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

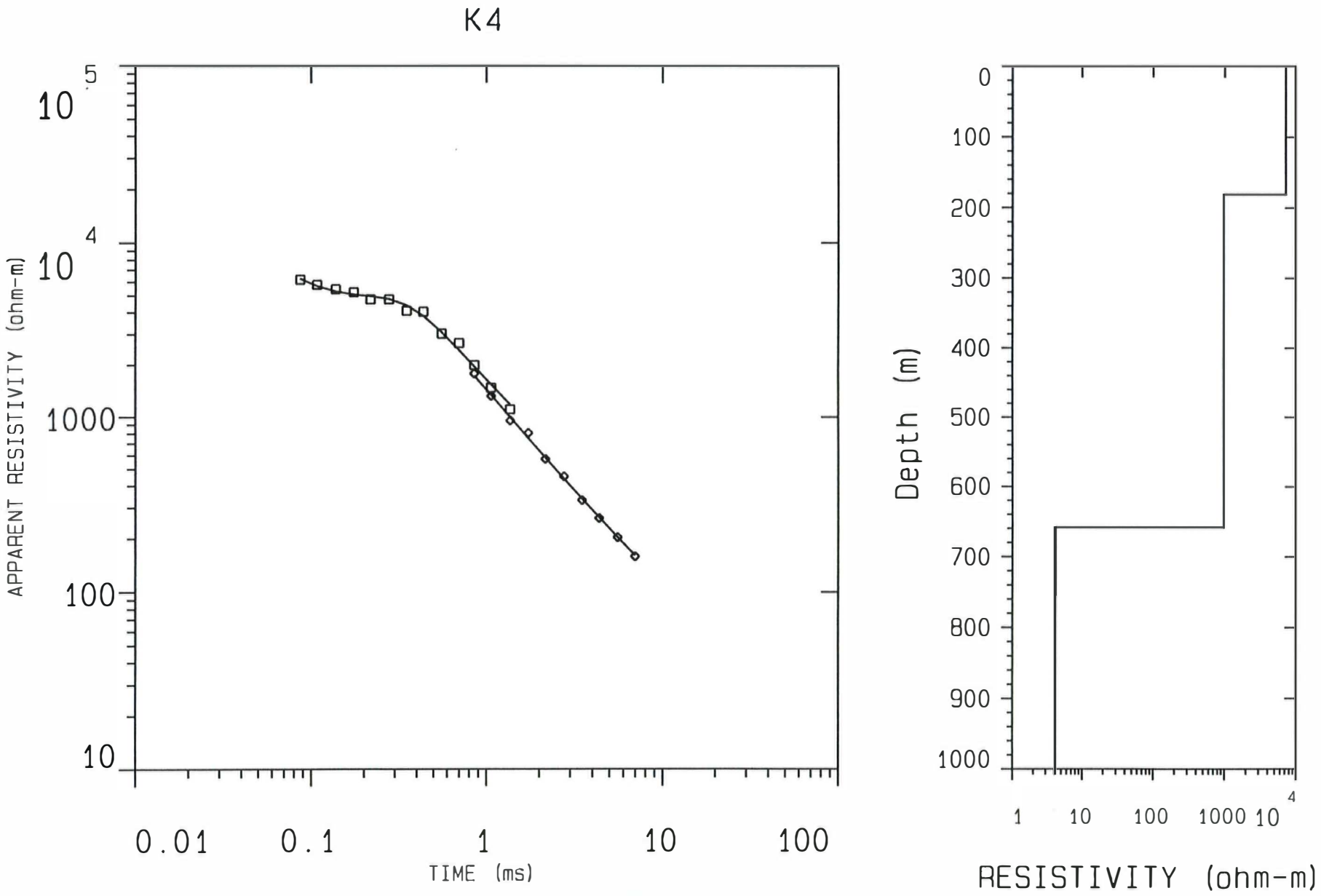
No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	1188.0	1175.0	1.09
2	0.108	816.4	830.7	-1.74
3	0.138	523.4	536.4	-2.47
4	0.175	323.8	333.7	-3.06
5	0.218	204.5	207.1	-1.24
6	0.278	122.0	119.8	1.78
7	0.351	75.06	72.13	3.90
8	0.438	48.76	47.19	3.22
9	0.558	33.40	32.43	2.91
10	0.702	23.99	24.50	-2.14
11	0.858	19.64	19.94	-1.53
12	1.06	16.12	16.17	-0.279
13	1.37	13.06	12.79	2.10

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 7 RAMP TIME: 210.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
14	0.857	22.72	23.26	-2.37
15	1.06	18.97	19.38	-2.16
16	1.37	15.91	15.90	0.0955
17	1.74	12.57	13.10	-4.24
18	2.17	10.79	10.96	-1.58
19	2.77	8.93	8.92	0.0525
20	3.50	7.41	7.28	1.72
21	4.37	6.06	5.95	1.81
22	5.56	4.81	4.73	1.81
23	6.98	3.92	3.76	3.91

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.09				
P 2	0.03	0.75			
P 3	0.08	-0.06	0.72		
T 1	0.16	0.24	-0.01	0.72	
T 2	-0.07	-0.12	-0.03	0.13	0.93
	P 1	P 2	P 3	T 1	T 2


K4
APPARENT RESISTIVITY (ohm-m)
10^5
10^4
1000
100
10
0.01
0.1
1
10
100
TIME (ms)
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1
10
100
1000
10^4
RESISTIVITY (ohm-m)

DATA SET: K4

CLIENT: KSBE DATE: 07-31-99
LOCATION: KAUPULEHU, HUALALAI RANCH SOUNDING: 4
COUNTY: NORTH KONA ELEVATION: 547.10 m
PROJECT: KAUPELEHU EQUIPMENT: Geonics PROTEM
LOOP SIZE: 457.000 m by 457.000 m AZIMUTH:
COIL LOC: 0.000 m (X), 0.000 m (Y) TIME CONSTANT: NONE
SOUNDING COORDINATES: E: 200.0000 N: 4.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 6.385 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(FT)	CONDUCTANCE (Siemens)
			547.0	1795.0	
1	5372.1	186.4	360.6	1183.0	0.0347
2	944.5	459.0	-98.37	-322.7	0.486
3	3.68				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	3184.977	5372.106	11606.826
	2	756.932	944.536	1098.891
	3	2.451	3.685	5.542
THICK	1	152.789	186.409	244.747
	2	408.585	459.065	499.259
DEPTH	1	152.789	186.409	244.747
	2	620.875	645.474	671.692

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 7 RAMP TIME: 202.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

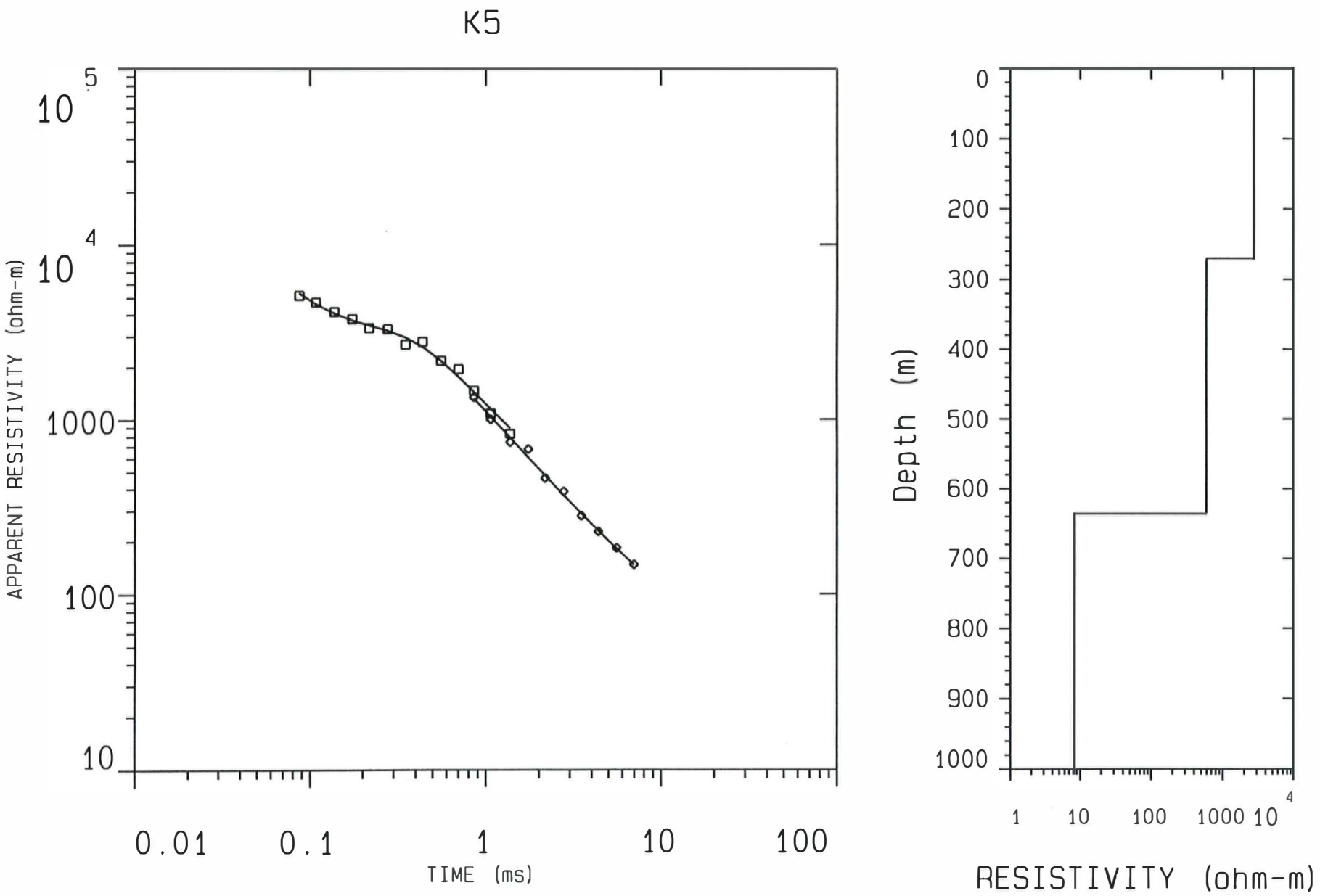
No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	1366.5	1366.8	-0.0248
2	0.108	875.9	907.0	-3.55
3	0.138	517.4	543.2	-4.99
4	0.175	302.2	315.6	-4.42
5	0.218	202.4	187.3	7.45
6	0.278	109.7	107.8	1.78
7	0.351	76.88	68.48	10.93
8	0.438	45.06	49.03	-8.81
9	0.558	37.97	37.14	2.19
10	0.702	25.82	30.04	-16.32
11	0.858	24.13	25.21	-4.49
12	1.06	22.02	20.97	4.75
13	1.37	18.15	16.84	7.20

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 7 RAMP TIME: 202.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
14	0.857	29.39	30.46	-3.65
15	1.06	26.48	26.07	1.52
16	1.37	23.28	21.78	6.43
17	1.74	16.61	18.31	-10.21
18	2.17	15.93	15.54	2.49
19	2.77	12.32	12.86	-4.38
20	3.50	11.03	10.68	3.20
21	4.37	9.07	8.87	2.21
22	5.56	7.31	7.19	1.71
23	6.98	6.14	5.83	5.09

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.05				
P 2	0.09	0.73			
P 3	0.06	-0.03	0.64		
T 1	0.09	0.32	-0.08	0.53	
T 2	-0.03	-0.13	-0.02	0.18	0.92
	P 1	P 2	P 3	T 1	T 2


K5
APPARENT RESISTIVITY (ohm-m)
10 5
10 4
1000
100
10
0.01
0.1
1
10
100
TIME (ms)
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1
10
100
1000 10 4
RESISTIVITY (ohm-m)

DATA SET: K5

CLIENT: KSBE DATE: 08-01-99
LOCATION: KAUPULEHU, HUALALAI RANCH SOUNDING: 5
COUNTY: NORTH KONA ELEVATION: 550.20 m
PROJECT: KAUPELEHU EQUIPMENT: Geonics PROTEM
LOOP SIZE: 457.000 m by 457.000 m AZIMUTH:
COIL LOC: 0.000 m (X), 0.000 m (Y) TIME CONSTANT: NONE
SOUNDING COORDINATES: E: 100.0000 N: 5.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 7.856 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(FT)	CONDUCTANCE (Siemens)
			550.2	1805.0	
1	2745.9	270.4	279.7	917.6	0.0984
2	588.2	366.0	-86.27	-283.0	0.622
3	8.30				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	1928.416	2745.996	4530.118
	2	432.955	588.212	751.932
	3	5.245	8.301	12.693
THICK	1	223.182	270.451	349.246
	2	302.437	366.022	422.115
DEPTH	1	223.182	270.451	349.246
	2	618.164	636.474	654.556

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 7 RAMP TIME: 210.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.0867	1799.9	1717.6	4.57
2	0.108	1186.5	1224.0	-3.16
3	0.138	775.6	801.2	-3.30
4	0.175	493.1	508.3	-3.06
5	0.218	342.0	324.5	5.12
6	0.278	190.1	196.3	-3.23
7	0.351	143.5	125.2	12.73
8	0.438	78.22	86.54	-10.63
9	0.558	62.22	62.40	-0.276
10	0.702	41.41	48.14	-16.25
11	0.858	38.45	39.42	-2.50
12	1.06	35.04	32.00	8.68
13	1.37	28.06	25.11	10.51

CURRENT: 14.00 AMPS EM-37 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 8 RAMP TIME: 210.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
14	0.857	43.83	44.96	-2.56
15	1.06	39.44	37.35	5.29
16	1.37	33.13	30.26	8.66
17	1.74	20.93	24.72	-18.09
18	2.17	21.42	20.40	4.76
19	2.77	15.16	16.38	-8.02
20	3.50	13.69	13.14	4.02
21	4.37	10.73	10.57	1.48
22	5.56	8.12	8.24	-1.37
23	6.98	6.39	6.43	-0.574

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.35				
P 2	-0.03	0.64			
P 3	0.12	-0.06	0.75		
T 1	0.23	0.24	-0.04	0.76	
T 2	-0.16	-0.18	0.00	0.17	0.87
	P 1	P 2	P 3	T 1	T 2